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# Feasibility Study on Direct Utilisation of Energy from Geothermal Brine – A Case Study of Olkaria Geothermal Power Plant, Kenya

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## ABSTRACT

Geothermal brine, a by-product of electricity generation contains a substantial amount of energy which, if tapped, can be used for a number of low heat energy applications. Possibility of application of brine energy from Olkaria geothermal power plant, Kenya has been assessed.

Brine produced at Olkaria Northeast field has an energy potential of 100 MWt. The biggest hurdle in utilisation of this energy would be silica scaling potential when the brine is cooled. Analysis of brine's chemistry shows that it can be cooled to 110$^o$C with no scaling problems and this would avail 26 MWt. A large market with energy demand of about 11 MWt exists within a radius of 30km among flower firms, tourist hotels and private home owners . Olkaria Northeast field potential therefore has more than twice the current energy demand.

Preliminary design shows that geothermally heated water can be piped to a distance of 30 km with heat loss of 5$^o$C and frictional pressure losses of 2.5 bars per km.


## 1. INTRODUCTION

Kenya relies on three major sources of energy, Biomass (70%), Petroleum (21%) and Electricity (9%). In the electricity sub-sector hydropower dominates with 57%, followed by fossil fuel (32%) and geothermal contributes to 11%. The other forms of renewable energy account for less than 1% (Mwangi, 2005).

Due to unreliable rain patterns, and the fact that Kenya depends highly on hydropower, electricity supply in Kenya is usually unreliable especially during the dry seasons. This has resulted in increased use of fossil fuels for electricity supply and due to the ever rising prices of fossil fuels, electricity price have become unaffordable to the majority of Kenyans especially the poor population. Lack of reliable and affordable electricity has hampered the country's development as industries and businesses come to a stand still during the long hours of load shedding or turn to use of expensive emergency diesel generator to meet their electricity demand. It has therefore become crucial to explore any available potential renewable energy so as to offer a reliable solution to the prevailing energy problem. In Kenya, geothermal energy can be used to replace a large percentage of fossil fuels for both electricity and thermal energy needs.

The Kenyan Rift Valley is endowed with a large potential of geothermal energy with an estimated potential of 4000 MWe (Mwangi and Mburu, 2005). Only 4% of this vast resource is currently being utilised.

## 2. BACKGROUND

All over the world, the major focus in the energy sector is on exploitation and utilisation of renewable energy sources especially those that are indigenous. In Kenya, such energy is geothermal energy. The Kenya rift valley has about 14 geothermal prospects (Figure 1) which has an estimated potential of 4000 MWe. This form of energy is renewable, indigenous and environmentally benign and can be used to replace fossil fuels in electricity generation and low heat energy utilisations.

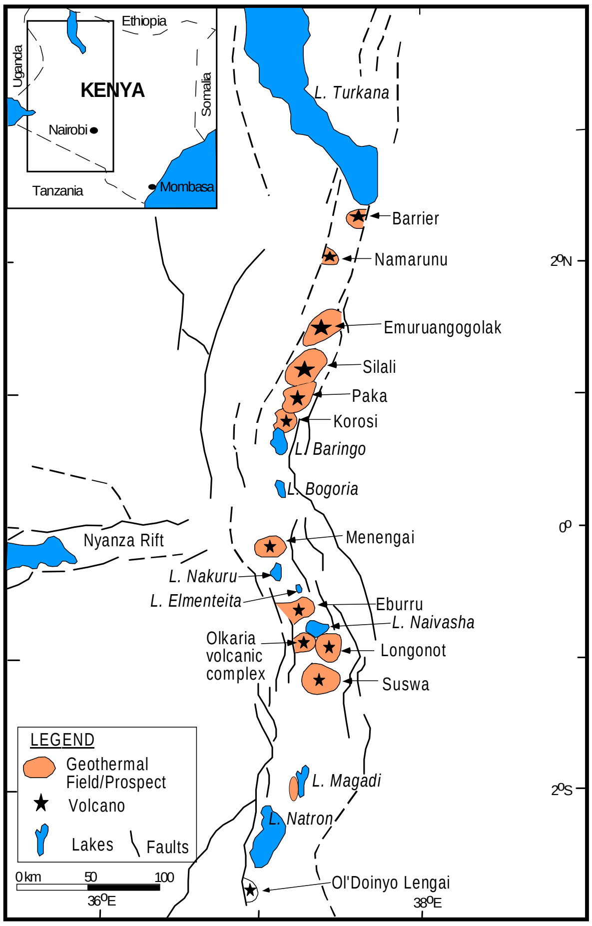


**Figure 1: Geothermal prospects within the Kenyan Rift (Omenda, 2003).**

Utilisation of geothermal energy in Kenya has not been optimised. When electricity is generated from geothermal energy, the brine generated is re-injected back to the reservoir at about 6 bars and 160$^o$C. At these conditions, the fluid still has ample amount of energy which can be utilised before the brine is eventually re-injected. Potential applications are in binary cycle electricity technology or for direct applications such as domestic hot water supply, greenhouse heating or space heating among others. At

Olkaria II power plants, about 140 kg/s of brine is generated. At this condition, the total energy potential of brine is about 100 MWt. This energy can be utilised before the brine is re-injected. One key factor to consider is the brine chemistry to ensure that amorphous silica scaling does not take place in the surface equipments when brine is cooled. If the chemistry is favourable, the brine can be utilised in provision of low heat energy direct applications.

Location of geothermal prospects in Kenya favour diverse modes of low heat energy utilisation, for example, absorption cooling applications would be ideal in the Northern part of the Rift Valley with characteristic semi arid climate of very hot days and quite cold nights. In the central and southern Rift, the geothermal energy is located in highly productive areas with majority of the population practicing arable and dairy farming. Nakuru town, one of the most productive area in Kenya is located near the Menengai prospect with an estimated 700 MWe. This prospect is the next target for development within the next 5 years (KenGen, 2004). Geothermal energy in such an area would be used in agricultural product pre-processing and preservation such as drying and cooling. Tourism activity in these areas would also be enhanced by ensuring that hotels and tourist centres are supplied with clean, environmentally friendly energy for heating, swimming, and other balneological uses.

The government of Kenya has created a special purpose company, Geothermal Development Company, GDC, to accelerate utilisation of geothermal energy in Kenya, utilisation geothermal energy is expected to increase drastically. Kenya power development plan has also shown that development of geothermal energy will be given priority (KenGen, 2004). This means that there will be large amounts of geothermal brine being generated which calls for early plans to be put in place to harness this abundant energy potential. This will then translate to large amounts of geothermal brine being generated. The brine can therefore be used for provision of low heat energy requirements in many parts of Kenya especially within the Rift Valley.

Studies on direct application of geothermal energy from brine have been done in many parts of the world (Lund and Freestone, 2000). These studies show that the major hindrance in the use of energy from geothermal brine is scaling of surface equipments such as heat exchangers, pipelines and re-injection wells due to amorphous silica polymerisation when brine is cooled. No detailed studies have been done at Olkaria geothermal power plants. A large database exists of geothermal wells chemistry, output and thermodynamic characteristics. The data has can be used to analyse the scaling potential of the brine.

The need to explore indigenous renewable energy sources coupled with large unutilised geothermal energy potential from Olkaria power plants brine are the major motivating factors. Other factors include large market potential for low heat energy, high fossil fuel prices and the unreliability of electricity supply in Kenya. Since the government of Kenya is planning to expand geothermal energy utilisation, this will avail more geothermal energy and there is need to plan for utilisation of this energy long before the energy becomes available.

## 3. NATURE AND CLASSIFICATION OF GEOTHERMAL FLUID

Utilisation of geothermal fluid depends heavily on its thermodynamic characteristics and chemistry. These factors are depends on the nature of the geothermal system from which the fluid originated. Geothermal fluids have been classified differently by different authors. Some authors have done so by using temperatures while others have used enthalpy (Dickson and Fanelli, 2004). The most common criterion is that based on enthalpy.

The resources are divided into low, medium and high enthalpy resources. Table 1 reports the classifications proposed by a number of authors.

**Table 1: Classification of geothermal systems.**

| | (a) | (b) | (c) | (d) | (e) |
|---|---|---|---|---|---|
| Low enthalpy resources | < 90 | <125 | <100 | ≤150 | ≤190 |
| Intermediate enthalpy resources | 90-150 | 125-225 | 100-200 | - | - |
| High enthalpy resources | >150 | >225 | >200 | >150 | >190 |

a. Muffler and Cataldi (1978).
b. Hochstein (1990).
c. Benderitter and Cormy (1990).
d. Nicholson (1993).
e. Axelsson and Gunnlaugsson (2000).

Depending on the enthalpy, geothermal fluid can be utilised either for electricity generation or direct applications. Electricity generation is the most important form of utilization of high-temperature geothermal resources while low to medium resources are better suited for non-electric (direct) application (Lindal, 1973). Figure 2 shows a schematic diagram of electricity generation from geothermal fluid.

This study focuses mainly on direct utilisation of energy from spent geothermal brine from high temperature geothermal system. This is what makes this study unique since direct applications have almost entirely been done using low to medium temperature geothermal systems (Gunnlangsson et al, 2003).

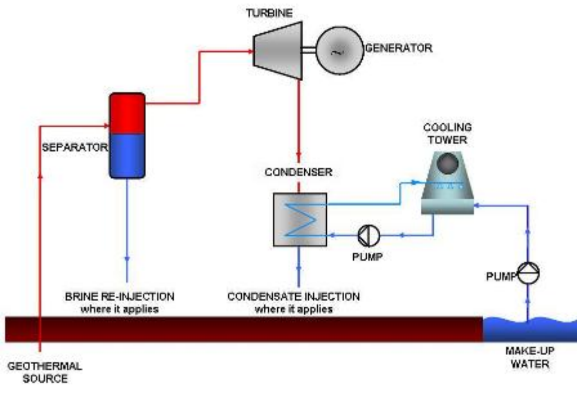


**Figure 2: Single-flash conventional electricity generation from geothermal energy (Dickson and Fanelli, 2004).**

### 3.1 Scaling Potential of Geothermal Waters

Chemistry of geothermal waters depends on the origin and temperature of the geothermal resource. Waters from high temperature resources have unfavourable chemistry for us unlike those from low temperature resources whose chemistry is quite mild and therefore favourable for uses.

Natural geothermal waters are saturated with silica in equilibrium with quartz and are frequently close to saturation with calcite, calcium sulfate and calcium fluoride.

Some highly mineralised waters of high temperature geothermal systems contain appreciable and near saturation of heavy metals. With changes in temperature and pressure, they are capable of depositing scales in piping and in surface drainage channels (Ellis and Mahon, 1977). The scaling problem is inherent to most liquid dominated geothermal resources. Generally, as aquifer temperature rises, the scaling problem would be expected along the extraction system (Grassiani, 2000). Scaling deposition and related phenomena were considered a major constraint on the development of geothermal energy worldwide (Gudmundsson, 1983 and Corsi 1987).

Silica and calcite are the most common and the most difficult to remove. While calcite has been mostly troublesome in production well management, silica is considered “dangerous” for re-injection wells and some parts of surface pipelines and transportation equipment. Empirical silica saturation curves and equations derived from laboratory research on pure and saline waters at different temperatures (up to about 350°C) serve as guidelines for the definition of silica super saturation, (Fournier and Marshal, 1983) and hence for the determination of temperature limit for brine disposal. When utilising high temperature water systems, detailed considerations must be given to the possibility of scale or deposit formation.

Scientists and developers are becoming more interested in research on minimisation of silica deposition. An increase in understanding will permit further use of spent geothermal brine issuing from moderate to high-enthalpy two-phase geothermal resources. To be certain that silica deposition does not occur, steam-water separation or heat exchange in utilisation schemes should not be planned to occur much below the temperature at which the water becomes saturated with amorphous silica. However, in practice, silica polymerisation and precipitation does not occur at a significant rate until a reasonable degree of super saturation is reached. The actual point will depend on the nature of the water (Arnorsson, 2000).

The strong relationship between pH and precipitation rate of amorphous silica has been observed. At the Fushima field in Kyushu, Japan, it was observed that low pH water has lower scaling potential than the neutral pH waters (Akaku, 1990). It was therefore concluded that in the Fushima waters, the pH controls the precipitation rate of amorphous silica more than the degree of super saturation. At Svartsengi, Iceland, studies on spent brine also showed that reducing the brine pH and brine dilution prevent silica deposition/polymerisation. Gudmundsson 1983 indicated that the rate of polymerisation of a solution initially supersatulated with respect to amorphous silica depends on the following factors.

- The initial degree of supersaturating.
- pH of the solution.
- Temperature.
- Presence of colloidal or particulate siliceous material.
- Ion concentration.

Arnorsson, 2000, reports that deposition of amorphous silica from super-saturated water, which is probably the most troublesome scale, could possibly be reduced, even inhibited, by rapid cooling of the water to less than 50°C before re-injection. Mixing of condensate and brine before re-injection should always be considered as a possible means of preventing scaling in injection wells.

High temperature geothermal brine of Nesjavellir power plant, Iceland are used to heat domestic water with minimal problems. Controlling the flow rate of the brine in the heat exchanger significantly reduces the possibility of silica scaling but reduces the heat transfer (Arnorsson, 2000). A detailed design takes into account of all conflicting factors to endure that it is both technically and economically feasible (Orme, 2003).

## 4. DIRECT UTILISATION OF GEOTHERMAL ENERGY

In many countries direct utilisation of geothermal energy is from low to medium temperature geothermal systems. The temperature of the fluid dictates the applications as illustrated by Lindal, 1973(Figure 3).

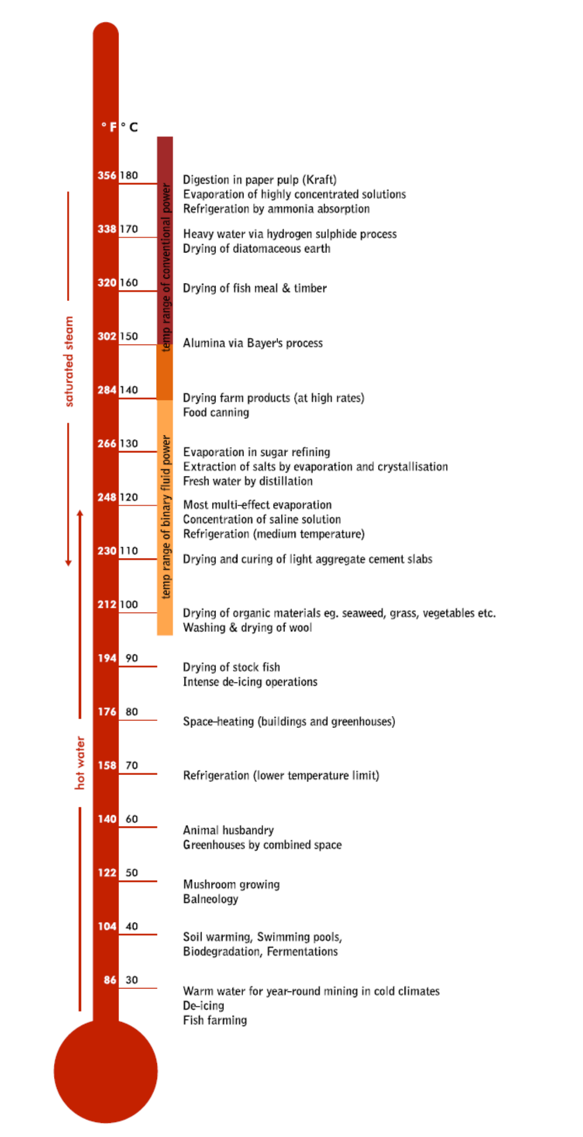


**Figure 3: Diagram showing the utilization of geothermal fluids (Lindal, 1973).**

Although there is great potential for both electricity generation and direct utilisation of geothermal energy in the Kenyan Rift valley, geothemal energy has been primarly used for electricity generation (Mwangi, 2005). Investigations into possible applications of this energy for direct applications show potential in swimming and other balneological uses, drying of farm produce, greenhouse heating and aquatic farming among other uses.

### 4.1 Greenhouse Heating

Heating of greenhouses using geothermal energy has been practiced in many countries in the world with encouraging economic, social and environmental benefits (Lund and Freeston, 2000).

In 2003, Oserian Development Company Ltd, a private firm growing rose flowers for export leased a geothermal well from KenGen for use in greenhouse heating. The two phase mixture (steam and brine) from this well are being used in a heat exchanger to supply hot water to heat 50 hectares of the greenhouses. In Kenya and other warmer countries,greenhouse heating is done primarily for humidity control to prevent fungal infection of plants. Heating lowers humidity and hence reduces uses e fungicides lowering production costs. Heating also enhances growth (Hole and Mills, 2003).

### 4.2 Domestic Hot Water Uses

District heating and domestic hot water supply using geothermal energy is dominant in many cold European countries. Though most of them use ground source heat pumps, those which have large geothermal resources like Iceland use geothermal energy (Fridleifsson, 2001).

Domestic uses of hot water include dish washing, laundry and bathing. Hot water consumption depends on uses and application temperature (Yao et. al., 2003). According to BRE, 2008, domestic hot water should be supplied at 60°C to avoid multiplication of Legionnaire bacteria (Figure 4) and to avoid scalding.

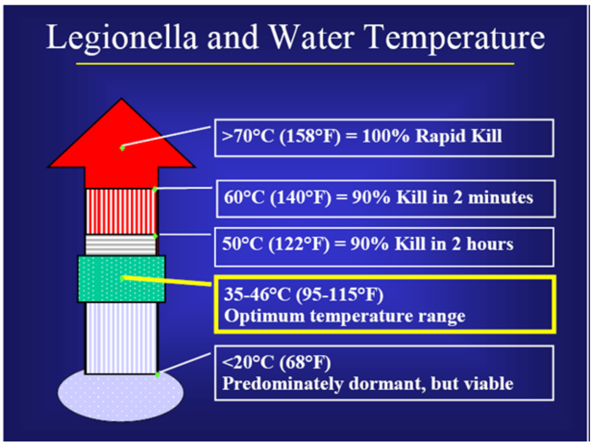


**Figure 4: Safe temperature domestic hot water (AWT, 2003).**

### 4.3 Leisure and Therapeutic Hot Water Uses

Water at elevated temperatures has been used for leisure and for its therapeutic potential for many centuries. Geothermal waters have in particular been used widely for these purposes. In Iceland for example, many tourist centres have geothermally heated pools, spas and steam bath. Blue lagoon, which uses geothermal brine from Svatsengi geothermal power plant, is a major tourist attraction with about 300,000 per year (Sigurgeirsson and Olafsson, 2003).

For safety and hygiene of swimmers, swimming pool water requires continuous cleaning and filtering at a circulation rate of between 4 - 8 hours. This depends on size and usage of the pool. A conventional commercial swimming pool 25m length, 10m width and average height of 1.5 m requires a circulation time of 6 hours (Dayliff, 2006). Water temperature at the swimming pool ranges between 26 - 30°C Saunas temperature must be between 80°C and 100°C while steam baths requires water between 43 - 60°C (Seneviratne 2007).

### 4.4 Crop Drying

Geothermal energy has been used to dry vegetables, fruits wheat and other cereals (Lund et al, 2005). Due to high solar radiation in Kenya, crops have been traditionally dried using solar energy. Farmers incur heavy crop losses due to the unreliability of solar energy during rainy and cold seasons and at night. Alternative energy sources have to be used during such times. Geothermal energy can be used as an alternative since it is reliable throughout the day all year round. Farmers in Eburru, Kenya use the geothermal energy to dry pyrethrum flowers (Mwangi, 2005). However, this is uncoordinated and is on a very small scale. When such activities are co-ordinated, they can be a major benefit.

### 4.4 Absorption Cooling

The absorption cooling uses heat energy to drive the cooling process (Figure 5). Absorption refrigerators are a popular alternative to regular compressor refrigerators where electricity is unreliable, costly, or unavailable, or where surplus heat is available.

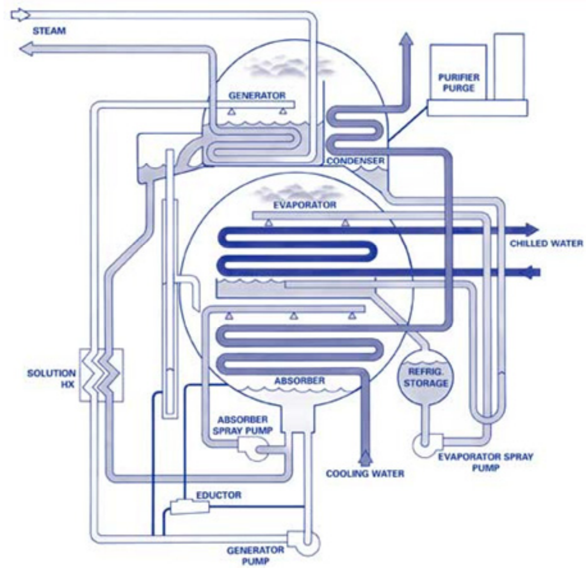


**Figure 5: A Schematic diagram of an Absorption chiller (energybooks, 2003).**

Heat from geothermal brine can be used as a primary energy source for absorption chillers. Hot water at 60 - 70°C can be used. After harvesting, cut flowers are pre-cooled before they are transported to the market. This ensures longer life and fleshness of flowers. Pre-cooling can be done through absorption chillers. Absorption chillers can also be used for storage of vegetable products or fresh fish.

## 5. FACTORS TO CONSIDER BEFORE PROJECT IMPLEMENTATION

### 5.1 Supply of Geothermal Brine

It is important to ensure that there is constant supply of the required energy to the customers. Geothermal power plants in Kenya are currently generating about 700 t/hr of hot brine from two power plants. Most of this brine is re-injected back to the reservoir (Mburu, 2007, Ofwona, 2007) and some of it can be used as a source of energy for direct applications.

Heat loss in hot water transmission pipeline depends on the diameter, the level of insulation, fluid flow rate, pipeline length and pipeline material (Gudmudsson and Lund, 1985). When designing pipelines for hot water transmission, the two key important factors to consider are heat and pressure losses. Heat loss is minimised by insulating the pipelines while pressure losses is affected by fluid flow velocity pipeline length (Ozisik, 1984). Effect of fluid flow velocity and pipeline length are illustrated in figure 6, for a pipeline of 150mm diameter.

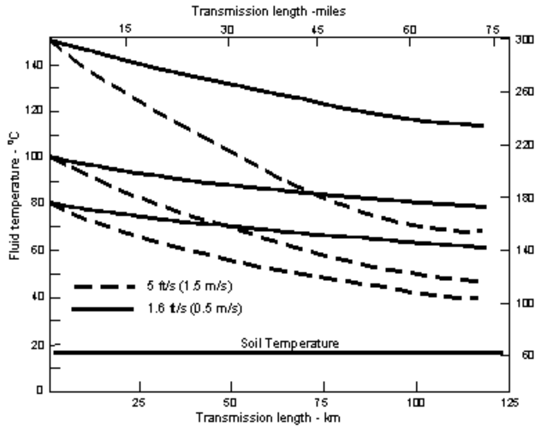


**Figure 6: Heat loss in hot water transmission line (Lund et al. 1998).**

The temperature loss in insulated pipelines is in the range 0.1 - 1°C per kilometre while that of un-insulated lines has an average heat loss of 2 - 5°C per kilometre for an average flow rate of 5 - 15 l/s. Heat losses are less for larger diameter pipes and for higher flows.

In Iceland, 450 mm diameter pipeline with 80 cm of rock wool insulation runs for 29 km (Nesjavellir to Reykjavik) and has less than 2°C loss. The pipeline runs above the ground and has a flow rate of about 560 l/s and takes seven hours to cover the distance. At low flow rates (off peak), the heat loss is higher than at greater flows (Gudmudsson, 1983).

### 5.2 Environmental Effects of Geothermal Brine

Geothermal fluids usually contain gases such as carbon dioxide ($CO_2$), hydrogen sulphide ($H_2S$), ammonia ($NH_3$), methane ($CH_4$), and trace amounts of other gases. It also has dissolved chemicals such as Sodium Chloride (NaCl), Boron (B), Arsenic (As) and Mercury (Hg) whose concentrations usually increase with temperature. These chemicals are a source of pollution if discharged into the environment 2000). Waste waters from geothermal plants also have a higher temperature than the environment and therefore constitute a potential thermal pollutant. Spent geothermal fluids therefore have to be re-injected back to the reservoir to avoid environmental contamination. Some geothermal fluids such as those utilised for district-heating in Iceland, contain low levels of chemicals and gas contents and therefore their disposal to the environment seldom a major problem they can therefore be cooled in special storage ponds and then discharged into surface waters (Kristmannsdottir, 1991).

Extraction of large quantities of fluids from geothermal reservoirs may give rise to subsidence phenomena. This is an irreversible phenomenon, but by no means catastrophic, as it is a slow process distributed over vast areas (Mariita, 2000). Over a number of years the lowering of the land surface could reach detectable levels, in some cases of the order of a few tens of centimetres and even metres, and should be monitored systematically, as it could damage the stability of the buildings. In many cases subsidence can be prevented or reduced by re-injecting the geothermal waste waters (Allis, 2000).

The withdrawal and/or re-injection of geothermal fluids may trigger or increase the frequency of seismic events in certain areas. However these are micro seismic events that can only be detected by means of instrumentation. Exploitation of geothermal resources is unlikely to trigger major seismic events, and so far has never been known to do so (Simiyu and Keller, 1996).

## 6. DISCUSSION

A study on the viability of using geothermal energy for direct applications in the horticultural, domestic and hotel industries show existence of a large potential market for geothermal energy utilisation and that there is a large capacity to supply the current demand with ample reserve to cater for future growth in energy demand.

### 6.1 Energy Uses and Demand

In Kenya, most potential customers use electricity and fossil fuels to meet their thermal energy requirements. With no domestic fossil fuel resources, electricity cost has increase significantly and has become unaffordable to the large population. Since hydro power contributes 57% of total electricity generation in Kenya, electricity supply is significantly reduced during dry seasons. This has a negative impact on many businesses especially those that rely heavily on electricity and fossil fuels to meet their energy demands. Heat from geothermal brine can be used to replace use of electricity and fossil fuels for low heat demand. This possibility should be given due considerations.

A few business premises within the study area have invested on renewable energy sources. Bila Shaka and Simba Lodge use solar energy in their premises while Oserian use geothermal energy to heat their greenhouses. These companies have indicated that investing in renewable energy technology is capital intensive but operation costs are negligible and use of this energy has opened more market for them. High investment costs are a stabling block to renewable energy utilisation. The government should provide grants or incentives to businesses investing on renewable energy sources if such ventures are to be successfully undertaken.

Table 2 shows the energy demand from the potential customers. The current demand stands at about 11 MWt. Analysis has been based on energy supply in form of hot fresh water at between 60 and 70$^{o}$C. Higher temperature water up to 90$^{o}$C can also be achieved with proper design. Geothermal energy can be used to meet most of the low quality heat energy demand.

**Table 2: Summary of hot water requirement by the potential customers.**

| Customer | Analysis based on | Quantity used | Energy requirement (MWt) |
|---|---|---|---|
| Greenhouse heating | Greenhouse area | 635 hectares | 4.6 |
| | Temperature increase required | $4^oC$ | |
| | Volume of greenhouse | $45.72x10^6m^3$ | |
| | Air circulation rate (ventilation) | 0.5 air change per hour | |
| Absorption cooling | Weight of flowers stored in all cold rooms | 100,000 kg | 2.5 |
| | Flower density in the cold stores ($kg/m^2$) | $20kg/m^2$ | |
| | Air circulation rate (ventilation) | 15 air change per hour | |
| | Temperature in the storage rooms | 2-5 $^oC$ | |
| Domestic hot water supply | Number of persons at KenGen estate | 1500 | 0.2 |
| | Number of persons at OrPower 4 estate | 200 | |
| | Number of persons visiting hotels daily | 300 | |
| | Hot water consumption for various uses | (Yao et. al,,2003) | |
| Leisure and therapeutic hot water uses | Number of swimming pools | 15 | 3.7 |
| | Swimming pool temperature | $30^oC$ | |
| | Temperature for other therapeutic hot | $35\text{-}40^oC$ | |
| | Other therapeutic hot water consumption | 25% of swimming pool | |
| **Total energy requirement** | | | **11.0** |
| Geothermal brine energy potential | Available brine | 140 kg/s | 26 |
| | Brine initial temperature | $160^oC$ | |
| | Brine pressure | 6 bars absolute | |
| | Transmission and distribution heat losses | 10% of available energy | |

### 6.2 Geothermal Brine's Thermal Energy Potential at Olkaria Power Plants

Olkaria geothermal power plants currently generates about 200 kg/s of hot brine at 6 bars saturation. 70 % of this brine is from Olkaria Northeast field, which supplies steam to Olkaria II. The rest is from the much older Olkaria East field, which supplies steam to Olkaria I power plant. More than 90% of brine from Olkaria East is not re-injected, but is directed to an infiltration lagoon near the power plant. Though this brine can be utilised, it is expensive to consolidate and use it because the steamfield design does not support this. Moreso, brine from Olkaria east field is much less. The Olkaria Northeast brine is all reinjected into four re-injection wells and therefore it is easier to utilise it before re-injection.

#### 6.2.1 Chemistry of the Olkaria Geothermal Brine

Brine at Olkaria northeast field has been analysed assess its scaling potential when when cooled. The most troublesome mineral in brine utilisation being amorphous silica, was the focus of analysis. The temperature to which further cooling would result to scaling was determined using a computer program WATCH (Bjarnason 1994). The WATCH programme helps to calculate the aqueous speciation of various components at several pre-determined temperature values for each mineral to obtain a log Q/K versus temperature relationship, (Jordan, 2000), where Q is the calculated value and K is the theoretical value. Though literature indicates that adjusting the brine pH can allow for brine cooling below silica saturation temperature. Cost-benefit analysis need to be carried out before such an undertaking.

Olkaria Northeast field has silica concentration of 500 - 700 ppm and a pH of about 9. Analysis shows that silica polymerisation would commence at temperatures below $110^oC$. However silica polymerisation and precipitation does not occur at a significant rate until a reasonable degree of super saturation is achieved, silica scaling problems are not experienced in practice until temperatures rather lower than the theoretical points are reached. The actual point will depend on the nature of the water (composition, presence and nuclei), (Arnorsson, 2000). This therefore means that the Olkaria brine can be cooled to less than $110^oC$ without any risk of silica scaling. This needs experimental analysis to establish how far the brine would cooled.

#### 6.2.2 Energy Available in the Geothermal Brine

The energy that can be mined from the geothermal brine depends on the temperature limit to which the brine can be exited from the heat exchanger. For $110^oC$ brine exit temperature, 30 MWt can be extracted from the brine at Olkaria northeast field. Allowing for 10% transmission heat losses, the available energy would be 26MWt.

The temperature to which the cold fresh water can be heated is determined by the amount of energy required (hot water demand) by the customers. Less energy demand can avail higher temperature while higher demand can avail lower temperatures. For safety and environmental reasons, domestic hot water is supposed to be transmitted at about $60^oC$ (BRE, 2008). For other applications such as absorption cooling and other non domestic application, hot water can be delivered to the customers at higher temperatures.

Heat from the geothermal brine is extracted using heat exchangers installed at the re-injection wells so as to maximise energy extraction and minimise the need for brine transmission which would trigger silica scaling. Heated fresh water is then to be piped to the customers.

### 6.3 Energy Transmission to the Customers

Factors to consider when determining pipeline sizes are the temperature and pressure losses. These losses are affected by pipe diameter, length, fluid flow rate, the level of pipeline insulation and cost. Since these factors are conflicting, an optimum operating value for each need to be determined detailed a design.

Analysis has shown that insulated pipelines have very low heat losses and it is possible to transmit water to a considerable length with less worry on heat losses. This study has shown that the hot water to the customers can be piped in a 350 mm diameter pipeline to a distance of 30 km. With a pipeline insulation of 10 mm, the heat loss in this pipeline is only $3^{o}$C. As long as the pipeline is insulated, heat loss cannot limit hot water distribution.

Pressure losses are critical in liquid transmission due to high liquid density. The main cause of pressure losses in the pipeline are the frictional forces between the fluid and the pipe wall when the fluid flows inside the pipeline. Since losses are directly proportional to the square of fluid flow velocity, doubling the fluid flow velocity results in four times the pressure losses while doubling the pipeline diameter results in half the amount of pressure losses. Detailed design seeks to optimise pipe sizes on the bases of heat and pressure losses as well cost. The recommended flow velocity for liquid transmission is 1 - 2 m/s (Lee, 2000). Other sources of pressure losses are in the pipeline fittings such as elbows, bends, reducers and valves. Pressure losses through these fittings are given in terms of equivalent frictional losses. These losses should be accounted for during the actual design.

Since the hot Olkaria II power plant is at a higher elevation than most all the customers (apart from a section of the housing estate) the hot water has a potential head of about 50m. This will reduce the pumping cost. When undertaking the detailed design, there is need to focus on how best to utilise the potential head available. To transport 150 kg/s of water at 1 m/s, a pipeline with a diameter of 350 mm has been recommended. Frictional loss in such a pipeline is 2.5 bars per km. A faster flow rate would result to increased pressure losses which would be uneconomical.

The hot water is to be piped in the 350 mm pipeline from Olkaria II power plant to the housing estate. Smaller pipelines will then distribute it to the potential customers. A detailed design for this is required.

### 6.4 Project Benefits

This project, if implemented will be beneficial to all the stakeholders and to the environment. The implementing company, GDC, and the customers will benefit directly while use of renewable energy will be beneficial to the environment.

Most of the potential customers interviewed indicated that their main source of energy for heating is electricity and fossil fuels. These energy sources are expensive and unreliable especially during the dry seasons. Supply of energy from geothermal sources is reliable since geothermal power stations are used as baseload and therefore brine is available all year round. This energy supply is expected to be cheaper than most of the current sources since it is derived from geothermal waste heat. A reliable, affordable energy source is what every investor would wish to have. And geothermal energy is an available solution.

Use of renewable energy has become the goal of most entrepreneurs. Most customers, especially those that are environmentally conscious want to buy goods and services which have little or no effects to the environment. Oserian for example have benefited from Fair Trade, a European Union organisation which targets products that are sensitive to the environment and to eradication of poverty (Transfairusa, 2008). Use of geothermal energy in hotels and in horticultural farms would open better market for the entrepreneurs and hence more income.

Implementation of this project would be a source of extra income to GDC because the company will sell the energy to the customers. With energy potential of 26 MWt derived purely from waste energy, and a ready market to supply 11 MWt, GDC’s implementation of this project will be quite beneficial.

Conservation of environment against any degrading factors is one of the main global focus today. The main concern currently is global warming resulting from carbon dioxide accumulation in the atmosphere. One of the main sources of carbon dioxide is burning of fossil fuels. Any energy source which can replace fossil fuels would be of great benefit to the environment. This project will help reduce carbon dioxide emission by replacing fossil fuels with renewable energy.

### 6.5 Project Hurdles

Although the project is feasible, there are potential hurdles which would, if not addressed, affect its implementation. These require careful investigations well before project implementation to avoid their potential effect.

Abstracting water from Lake Naivasha for commercial uses requires a licence from the necessary water authorities. GDC will therefore be required to comply with the licensing authority requirements before the licence is issued.

In order to be issued with a licence, one of the requirements would be to give a clear description of how the company intends to discard the spent water and at what temperature. GDC will transmit hot water to the customer in an open loop and therefore has no obligation on spent water disposal. Their only obligation will be on the spent brine. GDC need to advise the customers on the best ways to dispose off the spent water. The warm water can be used as gray water within the customers premises for such applications as irrigation, toilet flushing and laundry. The spent water can also be cooled in ponds to acceptable temperatures and then piped back to the lake.

This project is capital intensive. The largest cost is on transmission and distribution pipelines and storage tanks. GDC should be prepared to cater for the bulk of the cost for the energy supply project to be attractive to the customer, or source for funds from financiers to undertake this project. A detailed economic assessment of the project need to be done in order to determine the pay back period and hence the economic viability.

GDC partnership with customers would be quite beneficial to the project implementation. Such partnership may involve customers putting up distribution networks in their own premises. At this stage, it is not clear whether customers would be willing to undertake such a project or whether they would expect GDC to supply all the infrastructure and just bill them for the energy supply and use. If GDC would be required to lay down all the infrastructure, then an agreement has to be reached on who is responsible for damages, poor handling and incompetent operations equipment. There should be a clear policy on how to address these issues before the project implementation because if neglected, they can affect the smooth running of the project.

## 7. CONCLUSIONS AND RECOMMENDATIONS

Geothermal energy has been one of the key sources of electricity in Kenya since 1981 and has been identified as one of the least cost electrical power sources (KenGen, 2004). Potential direct utilisation of low heat energy from geothermal brine, a by-product of electricity generation, has been explored in this project and the following conclusions and recommendations have been arrived at.

### 7.1 Conclusions

The study shows existence of a large market for low temperature thermal energy utilisation in the horticultural sector, hotel industry and the individual homes. The energy is to be supplied in form of hot water.

Currently, most of the customers use electricity and fossil fuels to meet their needs. These sources are affected by external factors making their supply, cost and reliability quite unpredictable. Fossil fuel prices are currently very high and on the rise. Many people especially the poor cannot afford them. Electricity generation in Kenya is highly dependent on hydro power; this makes its supply inadequate especially during dry seasons. This therefore means that customers cannot meet their energy demand as they would wish and this has a negative impact on their business and comfort.

The total amount of brine generated from Olkaria power plants is currently about 200 kg/s of brine at 6 bars saturation condition from its two power plants. 140 kg/s of brine from Olkaria northeast field is suited for utilisation in the supply of low heat energy. This brine has a thermal energy potential of about 100 MWt. Thermodynamic and chemistry analysis show that 26 MWt can be tapped and utilised to provide low heat energy to a ready available market.

This research has shown that the current energy demand among the customers interviewed is about 11 MWt. The energy available is more than twice of the current energy demand.

The fresh water for heating can be obtain from Lake Naivasha or by drilling boreholes. The spent warm water should be used as gray water or can be cooled and piped back to the lake. Spent water disposal is entirely the role of the customers.

Preliminary design of hot water transmission pipeline shows that heat loss on an insulated pipeline is minimal. In a 350 mm pipe diameter, the heat loss is about $1^{o}C$ per 10 km if the flow is 1 m/s. Frictional pressure losses are 2.5 bars per km. Considering the elevations of hot water source and the customers, pumps have to be installed along the pipeline to boost the pressures. A detailed design will be required to address these requirements.

Most people in the domestic sector and hotel industry expressed need for space heating in their premises at night and during the cold seasons. There is therefore need to look into how much energy would be required for this application within the study area.

The study therefore shows that the project is feasible thermodynamically. There is a ready market for 42% of the energy available from brine. The project also has many benefits to all the stake holders and to the environment. The potential hurdles need to be addressed before the project implementation and a detailed economic analysis need to be done to establish the economic viability of the project.

### 7.2 Recommendations and Further Work

Although the project seems viable, the following aspects need to be addressed before the project is implemented.

1. A detailed design for the hot water supply system to the customers needs to be done. This will help establish the hot water selling price, the payback period and hence, economic viability.

2. Sources of cold fresh water need to be identified. Policy on water abstraction and use for commercial uses need to be clearly obtained from the necessary authorities. Any costs and penalties should be included in the project costing.

3. Since the supply of hot water will be through an open loop, GDC should make sure that the customers understand their responsibility in handling spent warm water. The spent water disposal strategies need to be clearly defined as the sole responsibility of the customers.

4. Since most customers expressed need for space heating, this and other potential applications of low heat energy within the study area need to be evaluated.

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